

## CLAIMS

1. A method for estimating camera motion parameters, the method comprising:

obtaining an observation point set including a plurality of observed point vectors;  
computing a plurality of motion output vectors by performing a recursive least squares (RLS) process based on a plurality of motion parameter vectors; and,  
comparing the plurality of motion output vectors to the plurality of observed point vectors.

2. The method as set forth in claim 1, wherein the computing a plurality of motion output vectors and the comparing the plurality of motion output vectors to the plurality of observed point vectors comprise:

initializing a first covariance matrix to a positive value;  
setting a first motion parameter estimate vector to an initial value;  
determining each of the plurality of motion parameter vectors, the determining comprising:  
computing a current covariance matrix;  
computing a current motion parameter estimate vector based on the current covariance matrix;  
computing a current motion output vector and a current state variable matrix based on the current covariance matrix; and,  
comparing the current motion output vector to the observation point set;  
and,  
repeating the determining a predetermined number of times.

3. The method as set forth in claim 2, wherein the obtaining includes obtaining  $m$  number of points and  $n$  number of observations for each of the  $m$  number of points; and the repeating includes repeating the determining  $n$  times.

4. The method as set forth in claim 3, wherein the setting a first motion parameter estimate vector comprises setting the first motion parameter estimate vector equal to  $[1 \ 0 \ 0 \ 0 \ 0 \ 0]^T$ .

5. The method as set forth in claim 4, wherein:

the computing a current covariance matrix comprises computing  $P_t = P_{t-1} + P_{t-1}\phi_t[I + \phi_t'P_{t-1}\phi_t]^{-1}\phi_t'P_{t-2}$ ,  $P_t$  being the current covariance matrix,  $P_{t-1}$  being the prior current covariance matrix,  $P_{t-2}$  being the second prior current covariance matrix,  $\phi_t$  being the current state variable matrix,  $\phi_{t-1}$  being the prior current state variable matrix, and  $I$  being the identity matrix; and,

the computing a current motion parameter estimate vector comprises computing  $\hat{\theta}_t = \hat{\theta}_{t-1} + [P_{t-1}\phi_t[I + \phi_t'P_{t-1}\phi_t]^{-1}]^T[y_t - \phi_t\hat{\theta}_{t-1}]$ ,  $\hat{\theta}_t$  being the current motion parameter estimate,  $\hat{\theta}_{t-1}$  being the prior current motion parameter estimate, and  $y_t$  being the current motion output vector.

6. The method as set forth in claim 2, wherein:

the determining further includes computing a random noise vector of the form  $e = [e_1 \ e_2 \ e_3]$ ;

the computing a current motion parameter estimate vector includes computing the current motion parameter estimate vector which includes a plurality of noise vector transformation parameters; and,

the computing a current motion output vector includes computing the current motion output vector which includes a transformation of the random noise vector.

7. The method as set forth in claim 6, wherein the obtaining includes obtaining  $m$  number of points and  $n$  number of observations for each of the  $m$  number of points; and the repeating includes repeating the determining  $n$  times.

8. The method as set forth in claim 7, wherein the setting a first motion parameter estimate vector comprises setting the first motion parameter estimate vector equal to  $[1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0]^T$ .

9. The method as set forth in claim 8, wherein:

the computing a current covariance matrix comprises computing  $P_t = P_{t-1} + P_{t-1}\phi_t[I + \phi_t'P_{t-1}\phi_t]^{-1}\phi_{t-1}'P_{t-2}$ ,  $P_t$  being the current covariance matrix,  $P_{t-1}$  being the prior current covariance matrix,  $P_{t-2}$  being the second prior current covariance matrix,  $\phi_t$  being the current state variable matrix including one of the plurality of random noise vectors,  $\phi_{t-1}$  being the prior current state variable matrix, and  $I$  being the identity matrix; and,

the computing a current motion parameter estimate vector comprises computing  $\hat{\theta}_t = \hat{\theta}_{t-1} + [P_{t-1}\phi_t[I + \phi_t'P_{t-1}\phi_t]^{-1}]y_t - \phi_t\hat{\theta}_{t-1}$ ,  $\hat{\theta}_t$  being the current motion parameter estimate including the transformed one of the plurality of noise vectors,  $\hat{\theta}_{t-1}$  being the prior current motion parameter estimate, and  $y_t$  being the current motion output vector.

10. A method for determining a filter to correct for camera motion errors, the method comprising:

determining a plurality of desired motion point vectors;

computing a plurality of estimated motion point vectors by means of an RLS algorithm; and,

computing the filter based on a difference between the plurality of estimated motion point vectors and the plurality of desired motion point vectors.

11. The method as set forth in claim 10, wherein:

the determining a plurality of desired motion point vectors comprises determining the desired motion as described by  $X_{t+1} = R_dX_t + T_d$ , where  $X_t$  is the motion

output matrix at time  $t$ ,  $X_{t+1}$  is the motion output matrix at time  $t+1$ ,  $R_d$  is the desired rotation matrix, and  $T_d$  is the desired translation vector;

the computing a plurality of estimated motion point vectors comprises computing the estimated motion as described by  $X_{t+1} = R_e X_t + T_e + c_e e$ , where  $R_e$  is the estimated rotation matrix,  $T_e$  is the estimated translation vector,  $c_e$  is a noise transformation matrix, and  $e$  is a random noise vector; and,

the computing the filter comprises:

computing a filter rotation matrix according to  $R_f = R_e - R_d$ ; and,

computing a filter translation vector according to  $T_f = T_e - T_d$ .

12. The method as set forth in claim 11, further comprising computing a corrected output according to  $X_{t+1} = R_f X_t + T_f + c_e e$ .

13. The method as set forth in claim 12, wherein the RLS algorithm comprises:

obtaining an observation point set including a plurality of observed vectors;

initializing a first covariance matrix to a positive value;

setting a first motion parameter estimate vector to an initial value;

determining each of a plurality of motion parameter vectors, the determining each of a plurality of motion parameter vectors comprising:

computing a current covariance matrix;

computing a random noise vector;

computing a current motion parameter estimate vector based on the current covariance matrix, the current motion parameter estimate vector including the noise transformation matrix;

computing a current motion output vector and a current state variable matrix based on the current covariance matrix, the current motion output vector including the transformed random noise vector; and,

comparing the current motion output vector to the observation point set; and,

repeating the determining a predetermined number of times.

14. The method as set forth in claim 13, wherein the obtaining includes obtaining  $m$  number of points and  $n$  number of observations for each of the  $m$  number of points; and the repeating includes repeating the determining  $n$  times.

15. The method as set forth in claim 14, wherein:

the initializing a first covariance matrix comprises initializing the first covariance matrix to a large positive value; and,

the setting a first motion parameter estimate vector comprises setting the first motion parameter estimate vector to  $[1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0]$ .

16. The method as set forth in claim 15, wherein:

the computing a current covariance matrix comprises computing  
$$P_t = P_{t-1} + P_{t-1}\phi_t[I + \phi_t'P_{t-1}\phi_t]^{-1}\phi_{t-1}'P_{t-2}$$
,  $P_t$  being the current covariance matrix,  $P_{t-1}$  being the prior current covariance matrix,  $P_{t-2}$  being the second prior current covariance matrix,  $\phi_t$  being the current state variable matrix,  $\phi_{t-1}$  being the prior current state variable matrix, and  $I$  being the identity matrix; and,

the computing a current motion parameter estimate vector comprises computing  
$$\hat{\theta}_t = \hat{\theta}_{t-1} + [P_{t-1}\phi_t[I + \phi_t'P_{t-1}\phi_t]^{-1}]y_t - \phi_t\hat{\theta}_{t-1}$$
,  $\hat{\theta}_t$  being the current motion parameter estimate,  $\hat{\theta}_{t-1}$  being the prior current motion parameter estimate, and  $y_t$  being the current motion output vector.

17. A system for estimating and filtering camera motion parameters, the system comprising:

- a movable digital camera for generating a plurality of 2-dimensional images of a scene or object;
- a control means for translating and rotating the camera along a predetermined trajectory;
- a computer system for receiving and processing the plurality of 2-dimensional images, the computer system including:
  - a user interface for receiving instructions from a user and for providing output to a user;
  - an image input means for receiving the plurality of 2-dimensional images from the camera;
  - a storage means for storing programs and the plurality of images;
  - a program to determine a desired motion, the desired motion described by  $X_{t+1} = R_d X_t + T_d$ , where  $X_t$  is the motion output matrix at time  $t$ ,  $X_{t+1}$  is the motion output matrix at time  $t+1$ ,  $R_d$  is the desired rotation matrix, and  $T_d$  is the desired translation vector; and,
  - a program to compute an estimated motion by means of an RLS program, the estimated motion described by  $X_{t+1} = R_e X_t + T_e + c_e e$ , where  $R_e$  is the estimated rotation matrix,  $T_e$  is the estimated translation vector,  $c_e$  is a noise transformation matrix, and  $e$  is a random noise vector.

18. The system as set forth in claim 17, further comprising:

- a program to compute a filter rotation matrix according to  $R_f = R_e - R_d$ ;
- a program to compute a filter translation vector according to  $T_f = T_e - T_d$ ; and,
- a program to compute a corrected output according to  $X_{t+1} = R_f X_t + T_f + c_e e$ .

19. The system as set forth in claim 17, wherein the RLS program includes:

- a program to obtain an observation point set including a plurality of observed vectors;
- a program to initialize a first covariance matrix to a positive value;
- a program to set a first motion parameter estimate vector to an initial value;
- a program to determine each of a plurality of motion parameter vectors, including:
  - a program to compute a current covariance matrix;
  - a program to compute a random noise vector;
  - a program to compute a current motion parameter estimate vector based on the current covariance matrix, the current motion parameter estimate vector including the noise transformation matrix;
  - a program to compute a current motion output vector and a current state variable matrix based on the current covariance matrix, the current motion output vector including the transformed random noise vector; and,
  - a program to compare the current motion output vector to the observation point set; and,
- a program to repeatedly use the program to determine each of a plurality of motion parameter vectors a predetermined number of times.

20. The method as set forth in claim 19, wherein:

- the RLS program is configured to obtain  $m$  number of points and  $n$  number of observations for each of the  $m$  number of points;
- the program to repeatedly use the program to determine each of a plurality of motion parameter vectors is configured to repeatedly use the program to determine each of a plurality of motion parameter vectors  $n$  times;

the program to set a first motion parameter estimate vector is configured to set the first motion parameter estimate vector to  $[1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0]^T$ ;

the program to compute a current covariance matrix is configured to compute  $P_t = P_{t-1} + P_{t-1}\phi_t[I + \phi_t'P_{t-1}\phi_t]^{-1}\phi_{t-1}'P_{t-2}$ ,  $P_t$  being the current covariance matrix,  $P_{t-1}$  being the prior current covariance matrix,  $P_{t-2}$  being the second prior current covariance matrix,  $\phi_t$  being the current state variable matrix,  $\phi_{t-1}$  being the prior current state variable matrix, and  $I$  being the identity matrix; and,

the program to compute a current motion parameter estimate vector is configured to compute  $\hat{\theta}_t = \hat{\theta}_{t-1} + [P_{t-1}\phi_t[I + \phi_t'P_{t-1}\phi_t]^{-1}]^T[y_t - \phi_t\hat{\theta}_{t-1}]$ ,  $\hat{\theta}_t$  being the current motion parameter estimate,  $\hat{\theta}_{t-1}$  being the prior current motion parameter estimate, and  $y_t$  being the current motion output vector.